Final Report for NASA Grant NAG2-1180

02/01/98 – 01/31/01

Title: Design Space Exploration for MDO on a teraflop computer.

Principal Investigators: Bernard Grossman, William H. Mason, and Layne T. Watson.

Institution: Multidisciplinary Analysis and Design Center for Advanced Vehicles, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

Objective: Make efficient use of massively parallel computation for exploration of high-dimensional aircraft-configuration design space.

Approach: Three directions have been pursued: First, fully distributed control and sophisticated termination detection techniques have been used to manage computation on massively parallel machines. Second, several different global optimization algorithms have been adapted to operate as explorers rather than local optima generators. Third, new visualization techniques and software tools have been developed to help visualize aircraft designs in high dimensional (>25) spaces.

Accomplishments: Three graduate students were partially supported under this grant:

- Denitza Krasteva: M.S. (Computer Science) 1999
- Chuck Baker: M.S. (Aerospace Engineering) 2000
- Amit Goel: M.S. (Computer Science) 2000

Publications supported by this grant:

D. T. Krasteva, L. T. Watson, C. Baker, B. Grossman, W. H. Mason, and R. T. Haftka, "Distributed control parallelism in multidisciplinary aircraft design", *Concurrency: Pract. Exper.*, 11 (1999) 435–459.

A. Goel, C. A. Baker, C. A. Shaffer, B. Grossman, W. H. Mason, L. T. Watson, and R. T. Haftka, "VizCraft: a problem solving environment for configuration design of a high speed civil transport", *Comput. Sci. Engrg.*, 3 (2001) 56–66.

D. T. Krasteva, C. Baker, L. T. Watson, B. Grossman, W. H. Mason, and R. T. Haftka, "Distributed control parallelism for multidisciplinary design of a high speed civil transport", in *Proc. 7th Symp. on the Frontiers of Massively Parallel Computation*, IEEE Computer Soc., Los Alamitos, CA, 1999, 166–173.

D. T. Krasteva, L. T. Watson, C. Baker, B. Grossman, W. H. Mason, and R. T. Haftka, "Distributed control parallelism for high speed civil transport MDO", in *Proc. 9th SIAM Conf. on Parallel Processing for Scientific Computing*, CD-ROM, SIAM, Philadelphia, PA, 1999, 9 pages.

D. T. Krasteva, C. Baker, L. T. Watson, B. Grossman, W. H. Mason, and R. T. Haftka, "Distributed control parallelism for multidisciplinary design of a high speed civil transport", in *Parallel Numerical Computations with Applications*, T. Yang (ed.), Kluwer Internat. Series in Engrg. and Computer Sci., Vol. 515, Norwell, MA, 1999, 119–140.

A. Goel, C. Baker, C. A. Shaffer, B. Grossman, R. T. Haftka, W. H. Mason, and L. T. Watson, "VizCraft: a multidimensional visualization tool for aircraft configuration design", in *Proc. IEEE Visualization '99*, San Francisco, CA, 1999, 425–428.

S. E. Cox, R. T. Haftka, C. A. Baker, B. Grossman, W. H. Mason, and L. T. Watson, "Global optimization of a high speed civil transport configuration", in *Proc. 3rd World Congress of Structural and Multidisciplinary Optimization*, Buffalo, NY, 1999, 5 pages.

C. A. Baker, L. T. Watson, S. E. Cox, B. Grossman, R. T. Haftka, and W. H. Mason, "Study of a global design space exploration method for aerospace vehicles", in *Proc. 5th NASA High Performance Computing and Communications Computational Aerosciences Workshop*, CD-ROM, Mountain View, CA, 2000, 10 pages.

C. A. Baker, L. T. Watson, B. Grossman, R. T. Haftka, and W. H. Mason, "Parallel global aircraft configuration design space exploration", in *Proc. High Performance Computing Symposium 2000*, A. Tentner (ed.), Soc. for Computer Simulation Internat., San Diego, CA, 2000, 101–106.

C. A. Baker, L. T. Watson, B. Grossman, R. T. Haftka, and W. H. Mason, "Parallel global aircraft configuration design space exploration", AIAA Paper 2000–4763–CP, in *Proc. 8th AIAA/USAF/NASA/ISSMO Symp. on Multidisciplinary Analysis and Optimization*, CD-ROM, Long Beach, CA, 2000, 8 pages.

The application of advanced parallel computational techniques such as fully distributed control, dynamic load balancing, termination detection, and pthreads to realistic aircraft configuration design problems has been thoroughly demonstrated. Novel visualization techniques such as parallel coordinates have been applied to high dimensional (29) design spaces, and a problem solving environment visualization tool (VizCraft) was developed to show planforms, airfoils, violated constraints, and compare design points in 29 dimensional space. A massively parallel version of a global direct search optimization algorithm, DIRECT, has been developed and static and dynamic load balancing strategies successfully integrated.

Significance: Krasteva's work with the 2048 node Intel Paragon at ORNL demonstrated that advanced computer science techniques such as distributed control and pthreads can be effectively applied to aircraft configuration design, and that high efficiency can be achieved on massively parallel machines for realistic engineering design problems. VizCraft, a visualization tool for aircraft configuration design, represents a notable attempt to visualize data in 29 dimensions. Baker's work has established the feasibility of a massively parallel version of a global direct search optimization algorithm, DIRECT. However, the algorithm has not been validated on a massively parallel machine due to lack of machine access and termination of the grant.

Status/Plans: The grant has been completed. It is unfortunate that we were not able to get access to a truly massively parallel machine, such as one of the ASCI machines, in order to validate our proposed algorithms, particularly the global direct search optimization algorithm.

Points of Contact: Bernard Grossman, Department of Aerospace and Ocean Engineering (0203), Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, `grossman@aoe.vt.edu`, 540-231-7648. William H. Mason, Department of Aerospace and Ocean Engineering (0203), Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, `mason@aoe.vt.edu`, 540-231-6740. Layne T. Watson, Departments of Computer Science (0106) and Mathematics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, `ltw@cs.vt.edu`, 540-231-7540.

`http://www.aoe.vt.edu/hpccp/hpccp.html`

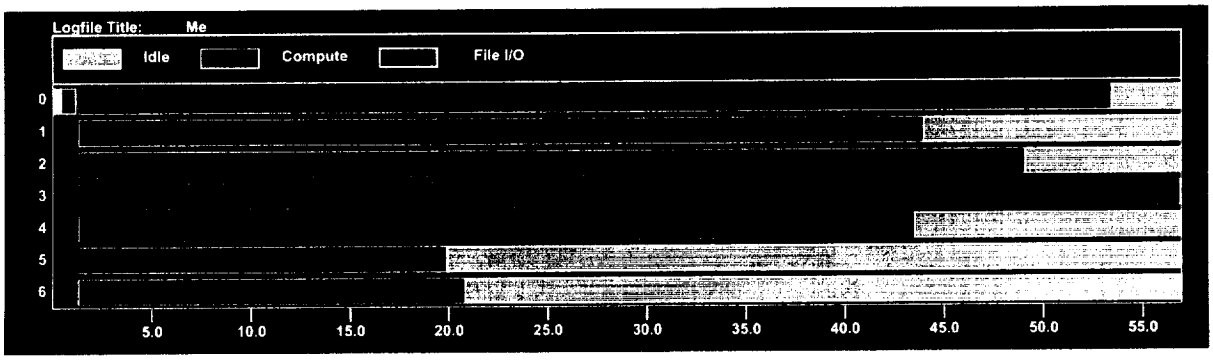

Figure 1. Snapshot from **nupshot** utility of static load distribution, P = 7.

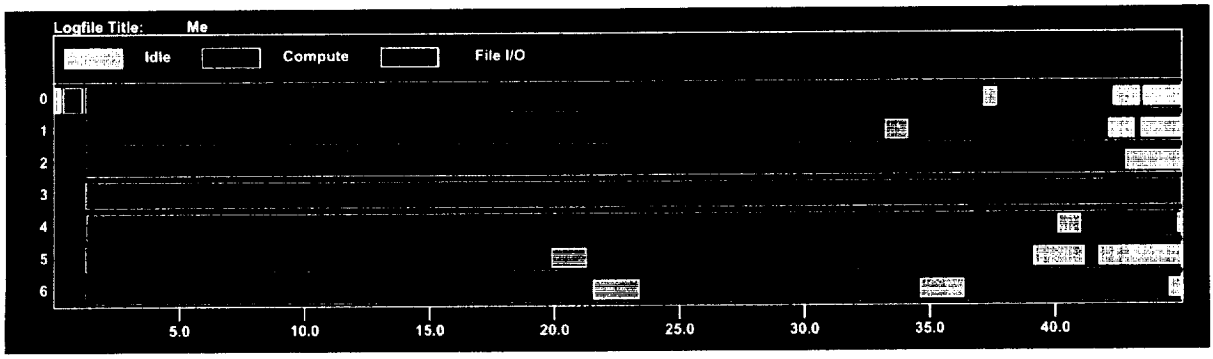

Figure 2. Snapshot from **nupshot** utility of GRR-MC with global task count termination, P = 7.

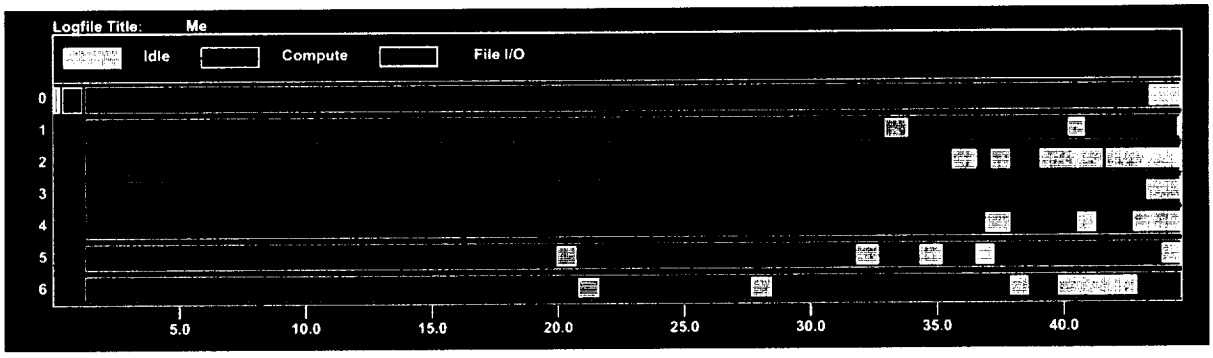

Figure 3. Snapshot from **nupshot** utility of RP with global task count termination, P = 7.

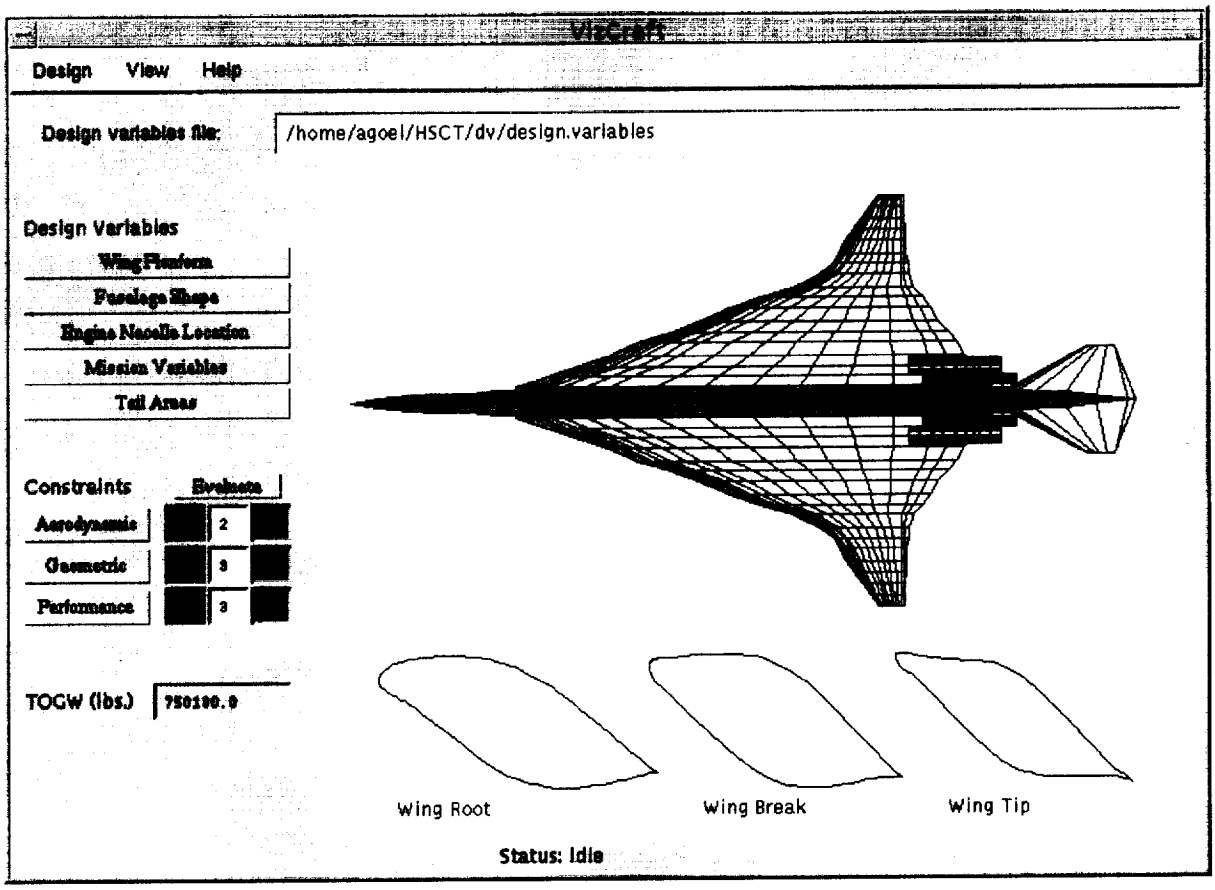

Figure 4. **Vizcraft** design view window showing aircraft geometry and cross sections of the airfoil at the root, leading edge break, and tip of the wing.

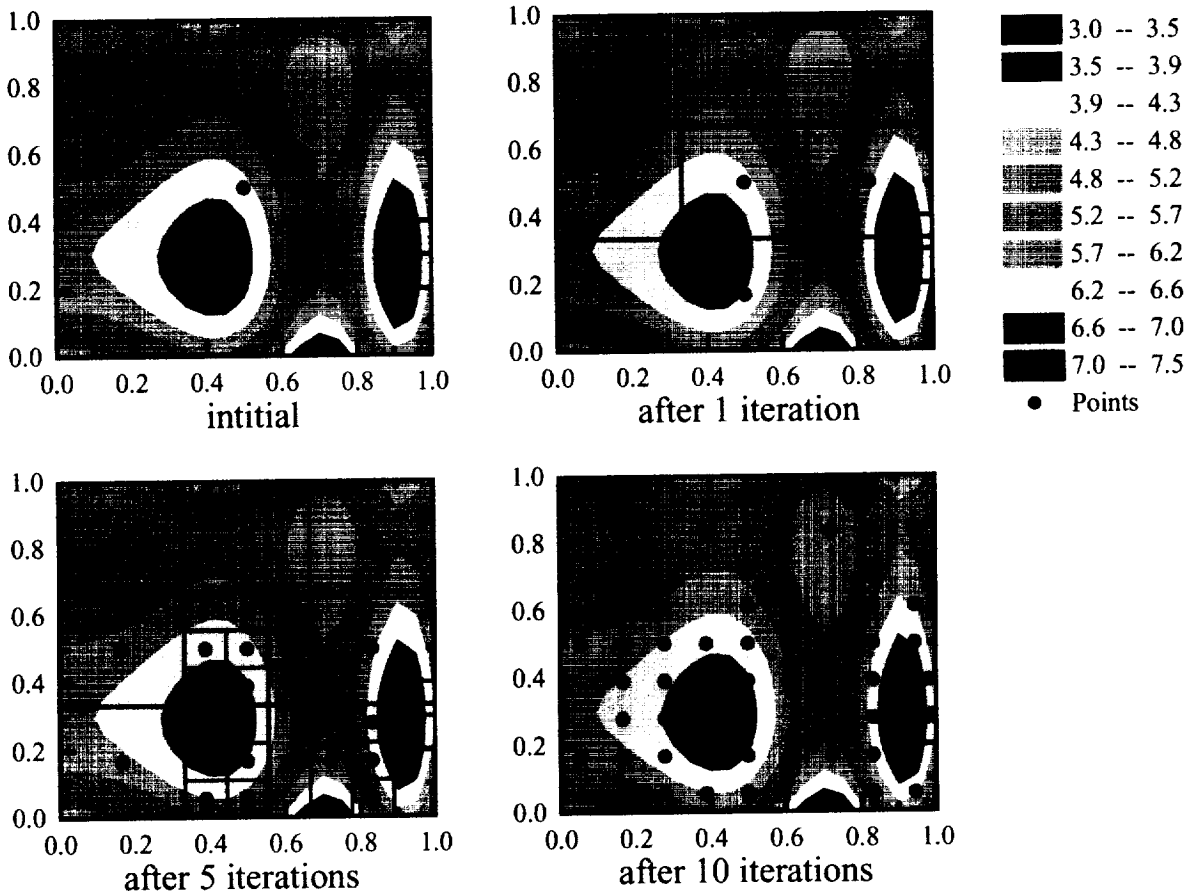

Figure 5. Sample problem indicating evolution of global search strategy in DIRECT. Contours indicate function to be optimized. Search does not get trapped in local optima.